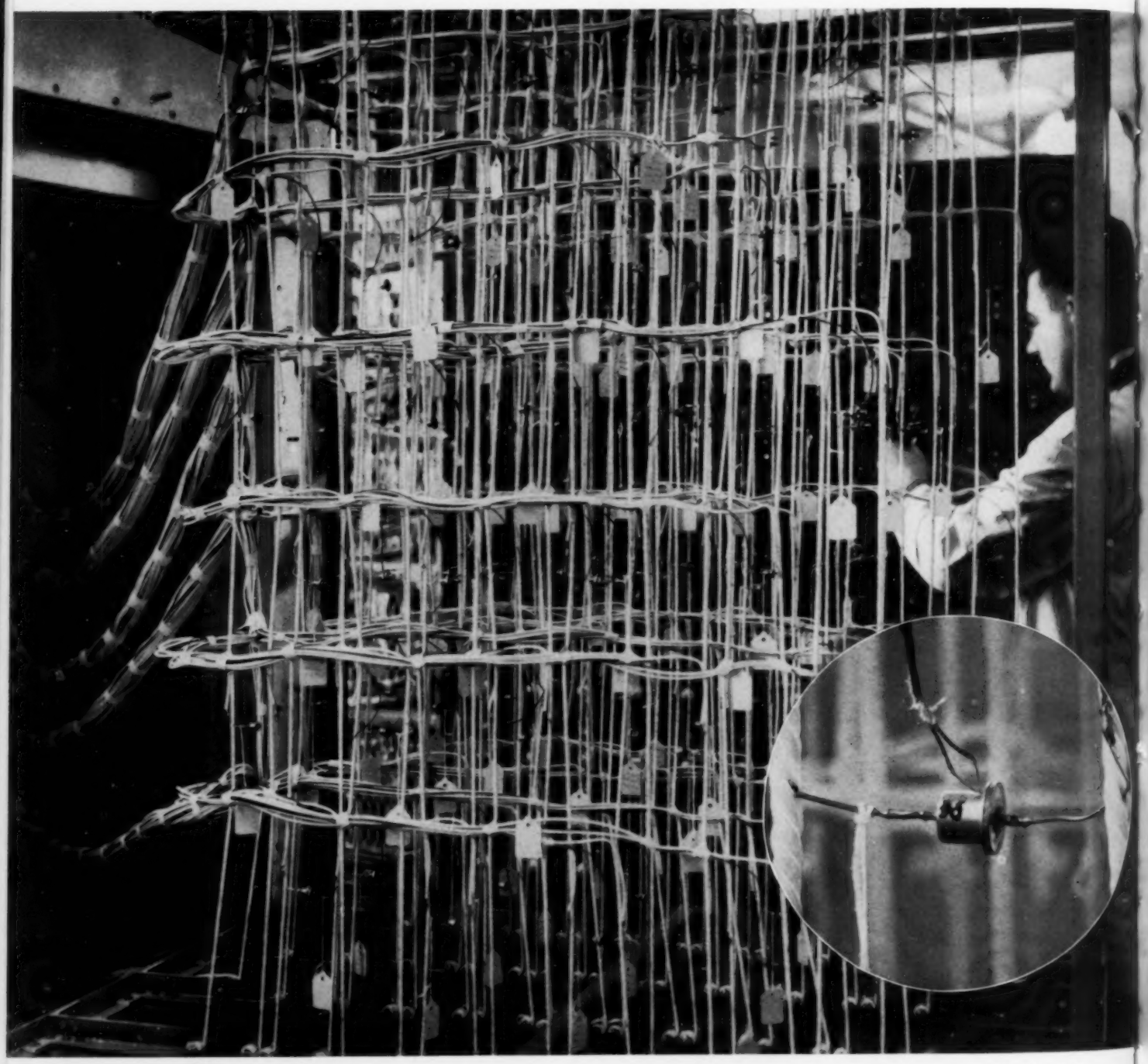
AUGUST
1956
VOLUME 5
NUMBER 8

Battelle Technical Review

IN THIS ISSUE:

Compressible Fluid Flow

Because electronic components are required to perform under extreme temperature, moisture, and other operating conditions, their reliability must be well established. Reliability studies of such components are carried out at Battelle with equipment which simulates widely varying conditions. In this view, rectifiers are mounted in the curtain-like net (see circular inset) for suspension in the environmental chamber. The performance of each component can be individually checked from the panel shown behind the frame.



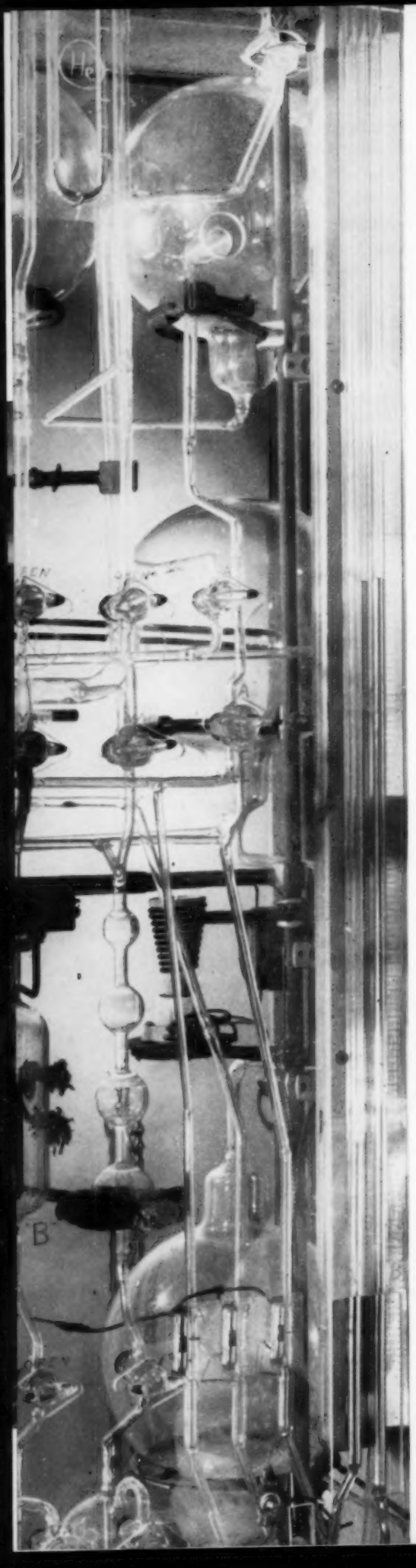
ELECTRONIC RELIABILITY STUDY

Volume 5, Number 8
August 1956

BATTELLE TECHNICAL REVIEW

Dedicated to the dissemination of knowledge. Published monthly by Battelle Memorial Institute, an endowed foundation serving mankind through science and technology.

Published monthly by Battelle Memorial Institute. Please address all correspondence about articles, abstracts, subscriptions, and exchanges to: The Editor, Battelle Technical Review, Battelle Memorial Institute, 505 King Avenue, Columbus 1, Ohio. Accepted as controlled circulation publication at Columbus, Ohio. Printed in the U. S. A.



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Abstracts of articles and papers in a wide variety of technological fields from more than 1350 journals published throughout the world. Abstract selection largely reflects the primary areas of Battelle research.

Adsorption apparatus used to determine surface area, porosity, and adsorption characteristics of solids.

"Doc" Harder --- A Builder of Battelle

THE PASSING OF DR. OSCAR E. HARDER brings to mind the many salutary characteristics he possessed that helped to make Battelle what it is today. The small group that Gillett assembled in the early days of the Institute possessed many of these characteristics, and it was the development of such qualities that established the strong foundation on which we have been able to build so big and lasting an edifice.

Just as in the case of Gil, aside from his basic morality, Doc's most outstanding trait was intellectual honesty. He made no compromise with expediency. He built up a *real* knowledge of his favorite subject, physical metallurgy, which was reinforced with a good understanding of the basic sciences. His objective was to apply his vast knowledge of metallurgy, both practical and theoretical, to useful purposes. Having applied it successfully in one place, he diligently searched out others. He was never satisfied that a given job was finished. He never rested on his laurels.

When he undertook a project in a specific field, he was not ready to plan a research program until he had mastered not only the metallurgical factors underlying the problem, but also had familiarized himself with the basic scientific and commercial considerations that would affect the project. Sometimes he had to go far afield to satisfy himself on the practical soundness of the contemplated research program.

In addition, Doc always kept himself informed on current metallurgical publications, which kept him equipped with a vast store of current as well as historical knowledge on every subject within his field of interest. In developing a research project, he devoted long, hard hours to study of the problem, utilizing every facility at his command to plan an effective, honest program that would move directly toward a solution. Not until then would he undertake actual physical research work. The same thoroughness, practicality, and energy were applied in the execution of the research study.

But aside from all these fine, technical qualities, Doc's greatest contributions were his teamwork—especially his friendliness, helpfulness to the younger research men, and his kindliness and sympathetic understanding toward all—and his intellectual integrity.

Doc Harder's part in the development of Battelle has been tremendous. His good work will be carried on.

Clyde Williams

President and Director,
Battelle Memorial Institute

VIGNETTE

GRAPHIC ARTS ADVISOR

J. Homer Winkler

Because of its importance in the communication and recording of information, graphic arts has been truly called the Mother of Progress. However, meeting the mounting needs for these services is a growing challenge to the industry. J. Homer Winkler of Battelle believes that the challenge can be met only if the industry applies research to its operations. At the same time, he recognizes that the prosecution of research is a major problem in an industry composed of so many small units.

Even before joining Battelle in 1944, Homer had sought ways of making research available to graphic arts firms. He has helped establish several cooperatively sponsored research organizations including Printing Plates Research, Inc., Photo-Engravers' Research, Inc., Gravure Research, Inc., and the Engraved Stationery Manufacturers' Research Institute. At Battelle, his responsibilities have been primarily related to the planning and guiding of research in the various fields of the graphic arts and in the pulp, paper, packaging, and, more recently, the textile industries.

A chemical engineering graduate of George Washington University at Washington, D. C., Homer early carried on research in electrotyping at the Bureau of Standards. As a research associate for the International Association of Electrotypers and Stereotypers, he investigated electrotyping operations. Later he became assistant manager of the Buffalo Engraving and Electrotype Company, then of the Ace Electrotype Company.

Homer is dedicated to the expansion of graphic arts research. Author of 15 technical papers, he has more than 50 general articles on graphic arts in print, many relating to research. He has made numerous talks to graphic arts groups of all kinds. He has also been active in more than a dozen technical and professional organizations. Recognitions of his contributions have been many, including election to the presidency of the International Association of Printing House Craftsmen and presentation to him of the Inland Printer Magazine Annual Award in 1952.

Homer and Mrs. Winkler have a son and daughter, both married, and three grandchildren. They like square dancing, but his wife has to control Homer's hobbies which include not only collecting original leaves of medieval manuscripts and foreign recordings, but all kinds of fine printing.

Compressible Fluid Flow

Though its development largely grew out of the needs of the aviation industry, compressible fluid flow is of increasing importance in the design of many types of industrial equipment

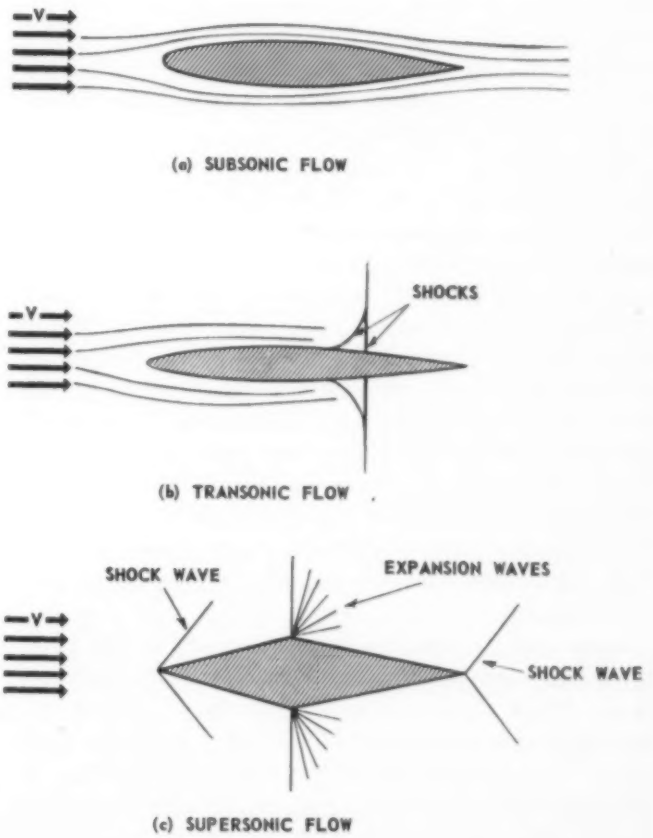
by Robert F. Badertscher *and*
Wilbur A. Spraker, Jr.

The science of fluid mechanics, which was born of the industrial revolution, has prospered over the last two centuries. As the industrial age burgeoned, so did those sciences associated with the mechanics of fluid flow. Until about the beginning of the twentieth century, however, most research in this field was centered about classical hydrodynamics, which deals with the flow of liquids. In the last 50 years, the emphasis has shifted to the study of gas flows, including compressible flows, boundary-layer flows, and flow over airfoils and bodies of revolution. This latter-day research has progressed far out of proportion to the continuing research on hydrodynamics.

Advances in the modern aspects of fluid mechanics have resulted from a number of causes. Normal scientific curiosity toward unsolved physical problems was originally a major factor. Later, the advent of the man-carrying airplane and its subsequent evolution into a wide variety of flight vehicles gave an impetus to the accelerated study of the flow of gases, such as air. Increased requirements for light, high-powered equipment, precise control of mechanisms, and transmission of power have also contributed to the study of modern fluid mechanics.

In the early decades of this century, most of the airflow problems under consideration dealt with low speeds. When a compressible fluid, such as air, moves at low speeds, its dynamic properties are essentially those of an incompressible fluid. With increases in speed, however, the dynamic properties change considerably from those of liquids. This is caused by the large changes in air density that occur at higher flow velocities. A measure of the effect of the speed on the density of a compressible fluid has been found in the ratio of the speed of a flow to the speed of a sound wave in the fluid. This ratio, commonly known as the Mach number, was named for an Austrian ballistician who first noted the importance of this ratio to calculations involving high-speed gas flows.

When a fluid, or a body immersed in the fluid, is moving at a speed lower than about one-half the speed of sound in the fluid, the flow can be mathematically approximated by considering the fluid as incompressible. Above that speed, however, the assumption of incompressibility leads to considerable error and is no longer valid. Before World War II, there were few reasons, other than scientific curiosity, to examine the flow of gases at speeds above Mach numbers of 0.5. Ballisticians were among the few exceptions to this general rule. They, of course, had been firing projectiles at speeds greater than the speed of sound (greater than Mach = 1.0) for many years. Most of their research, however, was empirical, rather than



1. *Subsonic, transonic, and supersonic flow over air foils illustrating the changes in air flow under these conditions.*

theoretical, and it relied heavily upon poorly instrumented experimental tests.

Just prior to and during World War II, the gas turbine engine and rocket engine were developed so that they could be used as the prime propulsion system for an aircraft. This effected a considerable revolution in the design and development of aircraft, making it possible for the first time to fly an airplane at speeds considerably above Mach = 0.5. The availability of such engines also made the rapid development of a usable theory for compressible gases at speeds considerably beyond Mach = 1.0 a military necessity. The scope of these developments was enormous since it covered not only airframe design, but engine design, aircraft accessory design, and air-intake design. The requirements for high-speed military air weapons has probably given the most significant impetus to compressible-fluid-flow research in recent years.

The aircraft industry is by no means the only industry concerned with the mechanics of compressible fluid flow. Steam power plants, for example, use high-velocity flows in turbines and through pipes. Other industries make use of compressed air or other gases for supplying power to tools or to actuate mechanisms. Still other industries are concerned with the design and development of high-performance heat-transfer units, compressors, blowers, and pneumatic control mechanisms. In each case, performance either has been or can be improved by application of the theory of compressible fluid flows.

Much space in today's magazines and newspapers is given to discussions of transonic aircraft, supersonic fighters, and hypersonic missiles. Each of the adjectives is derived from the vocabulary developed with new research in fluid mechanics. The speeds with which most persons are familiar are commonly called subsonic. That is, the speed is less than that of sound. Recalling the earlier definition of Mach number, subsonic flow can be defined as a flow in which the Mach number is smaller than unity everywhere in the system. Until 1947, no person had ever been transported at any speed greater than Mach = 1.0. In that year, Major Charles Yeager of the U. S. Air Force flew the Bell X-1 rocket-powered airplane at speeds greater than sound.

Since 1947, much has been published about transonic and supersonic speeds. Once again making use of the Mach number, a supersonic speed can be defined as one in which the Mach number is greater than unity everywhere in the system. Between the areas of subsonic and supersonic speeds lies the transonic region where the flow is partially subsonic and partially supersonic. Hypersonic flows are not quite as simple to define, although there is a range of supersonic speeds at which viscous effects of the fluid become predominant. This is the point where hypersonic flow is defined as beginning. In general, this change occurs at Mach numbers greater than 4 or 5.

In order to illustrate some of the phenomena associated with high-speed compressible flows, the discussion is divided into two parts—one on external flows and one on internal flows. In this discussion, the mechanics of flows over bodies submerged in a fluid are called external aerodynamics, while the internal flows are called internal aerodynamics.

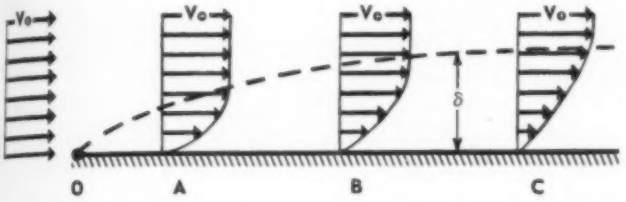
External Aerodynamics

Figure 1 is a diagrammatic representation of two-dimensional aerodynamic shapes in subsonic, transonic, and supersonic flows. The body is assumed, for simplicity of presentation, to extend to infinity perpendicular to the plane of the paper. These sketches

Robert Badertscher has carried on studies in aircraft and missile aerodynamics and performance, fluid mechanics, aerodynamic heating and heat transfer, and boundary-layer control since joining Battelle. Previously he had served as aerodynamicist with the Aeroproducts Division of General Motors, participating there in the design of transonic and supersonic propellers. He received both bachelor of aeroengineering and master of science degrees from The Ohio State University. He is a member of the Institute of Aeronautical Sciences.

Since joining Battelle, Wilbur Spraker has participated in investigations of heat transfer, fluid mechanics, and thermodynamics in aircraft propulsion and of industrial fluid mechanics systems. He came to the Institute with a background gained in numerous studies in the aircraft industry. As senior propulsion engineer at Convair Division of General Dynamics Corporation, Fort Worth, he investigated propulsion performance. He aided in research on the fluid dynamic design of nuclear reactors and the adaptation of gas turbine power plants to nuclear power at the NEPA Division of Fairchild Engine and Airplane Company at Oak Ridge. Earlier, Spraker had worked on the design and development of axial flow compressors at Pratt & Whitney Aircraft Company's plant at East Hartford, Connecticut. His degrees of B.S. in mechanical engineering and B.S. and M.S. in aeronautical engineering were received from Purdue University.

show the gross effects of compressibility on the flow of air over such shapes. Figure 1a represents a conventional airfoil shape in subsonic flow. Since the compression of the air is small, the pressure changes are not great enough to affect the density. The flow over the foil is then regular and easily examined mathematically and experimentally. Figure 1b is a schematic drawing and represents a high-speed airfoil shape in



2. *Diagrammatic sketch of the boundary layer on a flat plate.*

transonic flow. Since by definition there must be both subsonic and supersonic flow present, and since the two regions of flow are distinctly separate, there will be an area of discontinuity somewhere on the body. Theory and experimentation have shown that a flow can be accelerated from subsonic speeds to supersonic speeds smoothly and without any discontinuities. On the other hand, a supersonic flow cannot decelerate to subsonic speeds without an abrupt change in flow characteristics. This change is extremely rapid and has been given the name shock wave. These shocks are not easily apparent to the human eye, but they can be observed under test conditions with the aid of special optical devices.

Since a shock wave represents a large change in pressure, density, and temperature, the presence and location of the shock is of prime importance to an aircraft designer. At the present time, there is no exact, easily applied mathematical theory that will tell the designer all he wants to know about these shocks in transonic flow. Research is continuing, however, and it is probable that within the next few years good engineering solutions will be found for the general problem.

Figure 1c illustrates a supersonic flow over a diamond-shaped airfoil. This shape was selected for simplicity of presentation. As shown in the diagram, shock waves emanate from the nose and the tail of the airfoil. In addition, there are expansion waves at the inflection point at the thickest section. The oncoming air is compressed through the nose shock wave and the direction of the flow is changed to follow parallel to the airfoil surface. At the thickest point, the flow expands and changes direction again to remain parallel to the aft surface of the body. At the trailing edge, the flow must again pass through a shock, compressing the air to ambient pressure and realigning the flow parallel to its original direction. Each shock through which the flow passes represents an energy loss and consequently an increase in the resistance to the movement of the body through the fluid. This increase in resistance is generally called wave drag. The expansions present on the supersonic airfoil represent a gradual change in conditions that are free from energy losses.

Viscosity Effects

In addition to the basic problems of compressible and incompressible flow, an aerodynamicist must also consider the effects of the fluid viscosity. In 1903, Professor Ludwig Prandtl, of Germany, advanced the hypothesis that viscosity could be accounted for by considering a boundary layer. In this hypothesis, all viscosity effects occur in a thin layer of the fluid immediately adjacent to the body. Beyond this layer, the flow could be treated as a nonviscous fluid. Considerable research, both theoretical and experimental, has been performed to expand this theory.

Figure 2 is a schematic drawing that shows the general form of a boundary layer on a flat plate with the thickness greatly exaggerated for illustrative purposes. The initial, or free-stream velocity, V_0, reaches the plate at the point 0. The viscous nature of the fluid causes the fluid layers near the wall to decelerate to zero speed. Farther out from the wall, the velocity increases in a manner illustrated by the velocity profiles shown at points A, B, and C. As the flow progresses along the plate, the slope of the velocity profile increases because of loss in kinetic energy. The dotted line in Figure 2 is an exaggerated outline of the boundary layer that increases in thickness, δ, with increasing distance. A complete account of boundary-layer theory for both compressible and incompressible flow is too extensive to treat in this article, or even in a fairly large textbook. However, a discussion of the effects of the boundary layer on hypersonic flow is in order.

As the Mach number of a flow increases, the shock wave on the nose of a body in the flow inclines nearer and nearer to the surface of the body. In fact, at Mach numbers of 4 and above, the shock is inclined so far back that it almost coincides with the outer edge of the boundary layer on the body. When this occurs, the shock is likely to become detached from the body and form stronger shock some distance ahead of the nose. Since stronger shocks represent greater losses (more drag) they are to be avoided. At the present time, the amount of research that has been done at very high Mach numbers on shock-wave boundary-layer interaction is too small to form a complete basis for reliable

design. It is to be expected that such research will expand in the near future as more and better experimental facilities become available for empirical research.

Internal Aerodynamics

The first application of compressible flow relationships to internal flow systems was probably the de Laval turbine. Early steam turbines were usually of the impulse type in which the velocity of the stream did not change as it passed through the blades. Work was performed by changing the direction of the gas flow. Figure 3 shows a sketch of such a turbine.

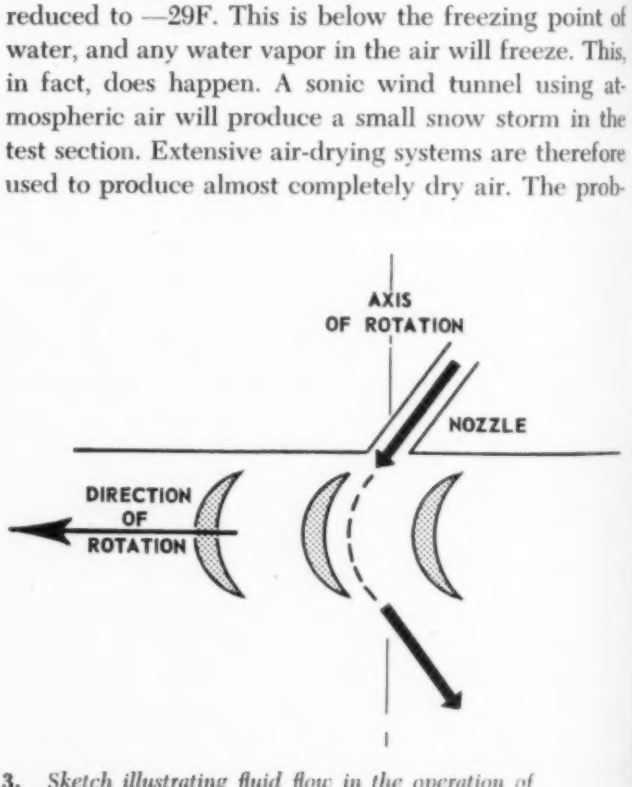
The output of a given turbine could be increased if the velocity of the entering and leaving steam could be increased. This was accomplished at first by increasing the pressure of the steam at the nozzle inlet. However, it was found that after the steam pressure had been raised to a certain value, further increases in pressure did not result in comparable increases in velocity, and that in fact the performance of the turbine might decrease. The solution of this problem was found in the compressible-flow relationships which led to a new design for the nozzle. The velocity of a gas or vapor flowing in a tube will increase as the cross-sectional area of the tube is decreased. Each increase in velocity requires a comparable increase in pressure at the inlet of the duct, since the contracting duct is essentially a mechanism for converting pressure into velocity. However, as pressure is further increased, a point is reached, as in the de Laval turbine, where further increases in pressure do not lead to an increase in velocity. The nozzle is then said to be "choked", which means that the gas is traveling at the speed of sound at the point of minimum area. At this point, the compressible-flow relationships exhibit an interesting change in their characteristics. If the gas has a velocity below the speed of sound, an increase in flow area will lead to a decrease in velocity; whereas if the gas has a velocity above the speed of sound, an increase in flow area will lead to an increase in velocity. The solution to the de Laval turbine therefore was to accelerate the gas to the speed of sound in a converging nozzle and to add a diverging nozzle immediately after the point of minimum flow area as shown in Figure 4. This allowed the steam to expand still further and the exit velocity from the nozzle became supersonic. An appreciable improvement in turbine performance was immediately possible. This application of the compressible-flow relationships is used today in both steam and gas turbines as well as in supersonic wind tunnels.

The performance of a nozzle depends not only on the variation of flow area through the nozzle, but also on the pressure difference available to force a fluid through the nozzle. For each gas or vapor there is a characteristic ratio between the pressure at the nozzle exit and the pressure in the supply upstream of the nozzle that will result in sonic velocity at the point of minimum flow area or throat. For air, this "critical pressure ratio" is approximately 0.53, and for steam approximately 0.57.

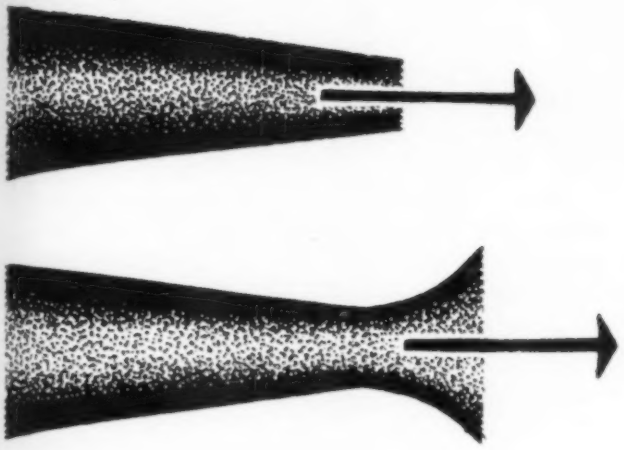
If the pressure ratio is less than critical, the gas can be further accelerated to supersonic speeds after passing through the throat. For each pressure ratio there is a maximum Mach number to which the gas can be expanded, and consequently a maximum increase in flow area downstream of the throat which the flow will follow. An attempt to accelerate the gas past the limiting Mach number will result in the formation of a shock wave in the nozzle, and the flow is said to "shock down" to a subsonic Mach number.

If the pressure ratio across a converging-diverging nozzle is greater than the critical value, the flow will be entirely subsonic. The flow will accelerate and reach some maximum speed less than sonic at the throat, and it will then decelerate through the diverging part of the nozzle.

The temperature of the gas in the supply upstream of the nozzle has an important effect on the flow. If air at 59F and 28 psia is accelerated to a Mach number of 1.0 at 14.7 psia, the temperature of the air will be reduced to —29F. This is below the freezing point of water, and any water vapor in the air will freeze. This, in fact, does happen. A sonic wind tunnel using atmospheric air will produce a small snow storm in the test section. Extensive air-drying systems are therefore used to produce almost completely dry air. The prob-



3. *Sketch illustrating fluid flow in the operation of an impulse turbine.*



4. *The converging nozzle (above) provides a velocity no greater than sonic while the converging-diverging nozzle will provide supersonic velocity if the pressure across the nozzle is sufficient.*

lem becomes more critical as the Mach number of the wind tunnel is increased to supersonic values. Carbon dioxide solidifies at an easily obtained temperature and the wind tunnel becomes a rather inefficient machine for making dry ice. Some modern tunnels would liquefy nitrogen and oxygen if the temperature of the air supply were limited to the usual room temperature values. To overcome such effects, the temperature of the air supply can be increased, allowing more expansion before the fluid temperature becomes so low that some portion of it condenses.

Unfortunately, temperatures desired by wind tunnel users to avoid condensation have now become so high that the temperature limits of the best structural materials would be exceeded. A major development program is needed to develop wind-tunnel facilities that will meet the requirements of designers of supersonic and hypersonic aircraft and missiles.

Industrial Applications

Studies of compressible flow have led to a commonly used controlling and measuring device, the critical flow orifice. Since pressure waves travel at the speed of sound, a nozzle or orifice with a critical pressure ratio across it, and consequently with sonic velocity in its throat, will not transmit a downstream pressure wave upstream through the orifice. Therefore, the flow through the orifice is determined only by the pressure and temperature of the gas upstream of the orifice. If the pressure and temperature of the gas upstream of the orifice are held constant, the flow will be constant. For most gases and vapors the flow is directly proportional to the upstream pressure over a fairly wide range. This allows a simple linear pressure-control system to be used to provide a linear variation in flow. The critical flow orifice is used in a wide range of applications for metering, instrumentation, and process control.

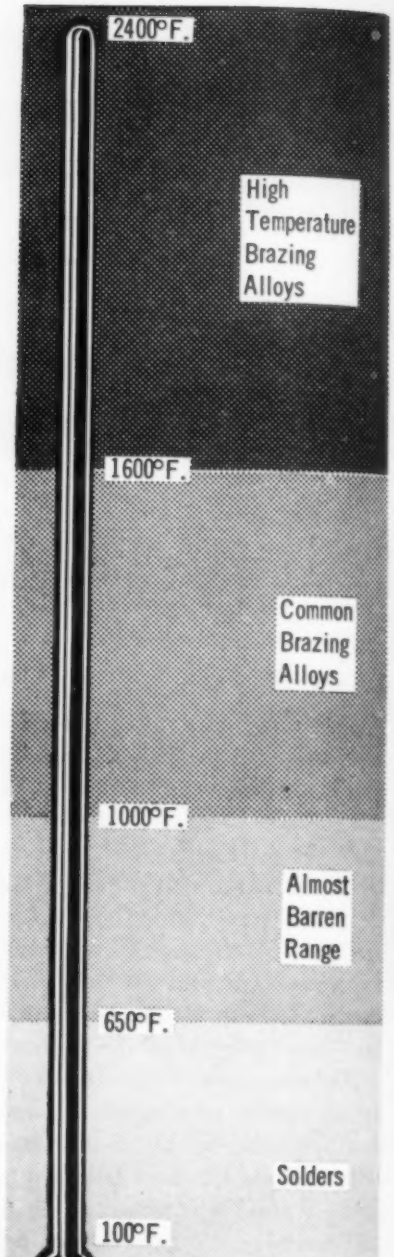
Consideration of compressible flow characteristics has become important in a number of flow systems in which the velocities are subsonic, but in which appreciable changes in the density of the gas or vapor occur. Gas pipelines are an important example. The determination of the optimum spacing of pumping stations on a pipeline requires an accurate prediction of the pressure losses in the pipeline. Calculations of these losses using only incompressible-flow relationships would lead to major inaccuracies since the pressure drop in the line caused by friction is sufficient to result in appreciable changes in the density of the gas. The velocity of the gas, for a fixed pipe diameter, continuously increases from one pumping station to the next. Since the frictional pressure drop is proportional to the square of the velocity, it is essential that the effects of density change on velocity be considered.

The design of heat exchangers with a gas or vapor on at least one side of the exchanger is another area in which compressible flow can play an important part. The entrance velocity to high-performance heat exchangers is usually in the low subsonic region. However, the combined effects of friction, which causes a decrease in pressure, and heat transfer, which causes a change in the temperature of the gas as it passes through the exchanger, lead to appreciable changes in the density of the gas. In the case of heat exchangers having a high pressure drop and a large temperature rise, it is possible to produce sonic velocity at the discharge of the heat exchanger. The compressible flow relationships, which can be written in a form which includes the effects of heat addition or subtraction, therefore describe very definite limits as to the maximum amount of that which a given system can transfer. A number of systems in the aircraft equipment and nuclear engineering fields are approaching these limits at the present time.

The effects of changes in density in flow systems have been relatively unimportant for many types of equipment. However, as the performance required of fluid systems increases, consideration of compressible flow characteristics can be expected to play an ever increasing part in the design, development, and prediction of performance of these systems. In many cases, the compressible flow relationship will do much to specify the design and performance limitations of new equipment.

High-Temperature Brazing

Because of its contributions to improved product design and possible applications in mass production operations, high-temperature brazing merits wider consideration in industry



by
ROBERT M. EVANS

BRAZING, A TECHNIQUE for joining metal parts, has been known for a long time, but it has been widely utilized in industry for only a couple of decades. Its use has grown rapidly as designers have increasingly recognized how the technique can contribute to the refinement of product design, reduction in product weight, and the application of mass production techniques. Already widely used for fabricating many automobile parts, refrigerator heat exchangers, surgical and dental tools, and vacuum tubes, new developments promise even wider applications, especially in high-temperature brazing.

In simple terms, brazing is accomplished by melting a nonferrous filler metal into a well-fitted joint formed by a number of metal parts. According to the brazing technologists, true brazing takes place only at 800 F or above. The process involves the use of a filler metal whose melting point is lower than that of the parts being joined. Moreover, the filler metal must wet the base metal and be drawn into the joints by capillary action. Any similar joining technique involving lower temperatures is known as soldering.

High-temperature brazing has been receiving increased attention in recent years. Because of its advantages as a technique for joining metal parts, brazing is being increasingly used in the fabrication of parts for planes, nuclear reactors, and other equipment operating at high temperatures. In this discussion, high-temperature brazing refers to processes using filler metals that melt above 1600 F and to techniques used to join assemblies subjected to temperatures of 1000 F or above.

The applications where brazed joints may be subjected to temperatures exceeding 1000 F are almost unlimited. The need for precision equipment operating at elevated temperatures is increasing at a rapid rate, and high-temperature brazing is meeting these requirements with its ability to permit fabrication of such equipment with a minimum of heavy mechanical fastenings.

A few examples will illustrate the extent to which designers are using high-temperature brazing. Turbine blades of turbojet engines have been brazed to the rotors to get good oxidation and heat resistance. Heat exchangers of all types are brazed with high-temperature, corrosion-resistant alloys for use in aircraft. Structures having high strength-to-weight ratios may be fabricated by brazing as, for example, high-strength air foils for use in the jet streams of aircraft. Other examples of high-temperature brazing applications are components for Diesel engines and metal-to-ceramic seals.

Present Brazing Processes and Techniques

Much of the credit for successful high-temperature brazing can be attributed to the development of exceptionally dry hydrogen furnace atmospheres. Brazed assemblies can be produced in hydrogen atmospheres without fluxes. Fluxes are used in the production of brazed joints but present a cleaning problem and a danger of weak joints because of entrapped flux.

Hydrogen brazing is a relatively old process. However, dry-hydrogen brazing as employed today differs in the degree of dryness of the hydrogen used. Hydrogen atmospheres must have dew points as low as —40 F or lower to braze metals such as stainless steel, Nichromes, Stellites, etc. which form refractory oxides. With closed brazing chambers and properly operated equipment, hydrogen with a dew point as low as —100 F is readily available.

The use of dry hydrogen atmospheres and careful design considerations permit the production of precision parts, complicated shapes, and multiple-part assemblies for use at elevated temperatures at costs much lower than heretofore possible.

Some metals, such as titanium and zirconium, which are useful for certain elevated-temperature applications, cannot be brazed in hydrogen because of possible gas contamination. Here, again, modern technology has supplied an answer to the problem. Improved vacuum techniques and the ready availability of inert gases such as argon and helium permit brazing these metals without fear of contamination by furnace atmospheres.

Other techniques are available for fabricating parts for high-temperature applications, but they cannot be called brazing techniques as such. However, they employ all the design requirements, joint preparation, and furnace techniques usually associated with brazing and, consequently, are considered whenever the advantages of brazing are desired. Examples of these processes are diffusion bonding and diffusion brazing. Diffusion bonding between nickel and stainless steel can be obtained by applying sufficient heat and pressure to closely mating parts. Diffusion brazing may be used to join many metals. By electroplating a second metal upon the base metal, a lower melting alloy is formed at the interface.

Another process, which involves brazing techniques, allows the production of specialty items for extra-high-temperature applications. Porous shapes of nonformable refractory materials, such as carbides, borides, cermets, etc., are infiltrated with filler metals to give strength and density. Under brazing conditions, capillary action completely fills the pores in the pressed shape with the filler metal.

Brazing Problems

In many cases the base metals used for high-temperature service contain significant amounts of metals that form refractory oxides. The oxides are detrimental to the brazing properties of these alloys because they prevent effective wetting of the base metals. Special techniques are often required to braze such metals. For example, Inconel X which contains titanium, can be brazed if an easily wettable metal is electrolytically plated on the surfaces to be brazed. Nickel or iron is often used for this barrier layer. Difficult brazing problems of this type can often be solved by proper plating techniques and controlled heating cycles. Electroless plating is used when the shape of the work pieces make electrolytic techniques difficult.

No summarization of the high-temperature brazing science would be complete without some mention of the precautions that are required. For example, considerable experience is required to secure and maintain

Since joining Battelle in 1943, Robert Evans has worked extensively in the field of nonferrous metallurgy. More recently, his investigations have been concerned with brazing, soldering, and tinplating. He has participated in studies relating to the forming and casting of nonferrous metals, the development of alloys, metal coloring, and bronze casting. He has also aided in the development of mineral-base lubricants for forming metals and in the investigation of borides resistant to molten zinc. A graduate of The Ohio State University with a B.S. in metallurgy, he is an active member of the American Society for Metals. He also serves on several joint committees of the American Welding Society and the American Society for Testing Materials.

dew points low enough to insure satisfactory brazes in hydrogen atmospheres. Fluxes are sometimes used in conjunction with atmospheres and, in such cases, a wetter atmosphere can be tolerated. However, the use of fluxes is prohibited if there is much difficulty in removing them. Parts to be brazed must be carefully cleaned and the cleaning methods vary with the materials being brazed.

The clearances in joints areas are extremeley important and should vary with the base and filler metals being used in order to assure satisfactory joining. Even variations in the composition of the filler metal may require alterations in the clearances for ideal brazing conditions.

Perhaps the most important requirement for successful high-temperature brazing is a sound knowledge of the brazing characteristics of the metals being joined. For example, Inconel can be readily brazed when the proper techniques are used, but it is virtually impossible to braze Inconel X under the same conditions. The titanium and aluminum, in the latter, form refractory oxides which inhibit the flow of the filler metal unless special brazing techniques are used.

Brazing-Filler Metals

Many alloys are available as high-temperature brazing-filler metals. However, only a relatively few are used because of cost, lack of experience in their use, or metallurgical problems connected with their application. As the requirements for high-temperature filler metals increase and more experience is obtained, it is expected that the less common metals will receive greater attention.

Copper. Among the high-temperature brazing-filler metals, the first to be considered is pure copper. When it is used in applications where the environment is neither very corrosive nor very oxidizing, copper is an effective filler metal. In the automotive industry, torque converters are assembled by copper brazing techniques, because the process is easily adaptable to the mass production of many complex articles at low cost. The numerous parts of the torque converter are tack-welded in a jig and then joined by copper brazing. Other precision parts are press fitted together and then copper brazed. The latter technique takes advantage of one of the chief attributes of copper as a filler metal. Because it is free flowing, the metal will sometimes plate an entire assembly by its excellent wetting properties. With proper joint designs, jigging, cleaning, and other preparatory operations, most of the common metals can be brazed with copper.

TYPICAL AREAS OF EXPANDING USE OF HIGH-TEMPERATURE BRAZING

Aircraft

Engine Parts—*valves, propeller assemblies*
Fuel Systems—*pressure tubing, nozzles*
Sandwich Structures—*wing surfaces, cowls*
Heat Exchangers—*superchargers, air heating*

Missiles

Fuel Systems—*injectors, tanks*
Precision Parts—*nose pieces, servo equipment*
Instrumentation—*guiding devices, temperature controls*
Power Plants—*burner assemblies, exhaust chambers*

Mechanical Power

Pressure Systems—*valves, piping*
Turbine Parts—*blades, nozzles*
Heat Exchangers—*boiler parts, preheaters*

Nuclear Power

Heat Exchangers—*reactor cooling, heat transfer*
Fuel Elements—*fuel protection, subassemblies*
Pressure Systems—*valves, piping*
Instrumentation—*reactor controls, electronic devices*

Nickel-Base Alloys. Among the most common brazing-filler metals with the ability to withstand high-temperature service in air and in corrosive environments, are the nickel-base alloys. These alloys usually contain nickel and chromium with small concentrations of other elements to lower the melting temperature and/or to promote flow and wettability. Most of these alloys are used in the powder form since they are nonformable.

An alloy typical of this class contains approximately 72 per cent Ni, 16 Cr, 4 Si, 4 Fe, and 4 B. It is considered a standard brazing alloy (BNiCr) by the American Welding Society and the American Society for Testing Materials, because of its widespread use. Its brazing temperature is about 2050 F. This alloy has almost industry-wide use where brazed assemblies for high-temperature applications are produced. It is highly corrosion resistant and possesses good oxidation resistance up to 2000 F. In many cases, the strength of the brazed joint equals that of the base metals: this

property is common to many of the nickel-base filler metals. Since interdiffusion between the base metal and the filler metal often raises the melting point of the filler metal itself, brazed assemblies can often be used at temperatures exceeding the actual brazing temperature. In spite of this advantage, it is sometimes desirable to braze assemblies of thin sheets and keep diffusion at a minimum. Careful alloy placement, controlled heating rates, and full utilization of capillarity help overcome this problem.

Another nickel-chromium alloy has been developed for use in nuclear reactor applications where the presence of boron in a filler metal is almost intolerable. Strong, oxidation-resistant brazed assemblies have been produced with an alloy composed of 66 per cent Ni, 20 Cr, 9 Si, and 4 Fe: boron is replaced by silicon.

The rather wide compositional variations of nickel-base alloys permit a choice of alloys for a specific end product; however, considerable experience in the use of the alloys is required. Conditions which permit satisfactory brazing with one alloy may not be suitable for another.

Miscellaneous Alloys. The brazing-filler metals already discussed are not the only ones which have shown promise for high-temperature brazing. Perhaps the best known alloy outside the nickel-base alloys is a filler metal containing 85 Ag — 15 Mn. It is recognized by the AWS-ASTM as a standard brazing alloy with the designation BAgMn. Molten at 1775 F, the alloy is used chiefly for joining stainless steels and high-nickel-base metals and has shown great promise in joining sandwich structures which possess high strength-to-weight ratios. The silver-manganese filler metal does not seriously embrittle the very thin stainless steel foils used in sandwich structures.

A number of alloys containing palladium, such as Pd-Ni, Ag-Pd-Mn, and Pd-Ni-Cr, have been used for special high-temperature applications. These alloys melt at higher temperatures than the nickel-base alloys and have a brazing-temperature range of 2250 to 2350 F. They exhibit excellent wetting characteristics on most of the heat-resistant base metals, but produce joints with poor ductility. At temperatures above approximately 800 F, these alloys scale badly.

Some other alloys have been used for high-temperature applications, but their use is rather limited because of their physical characteristics or because they have not been developed to the point of commercial use. Among these are several ternary alloys containing phosphorus to lower the melting point of the nickel, chromium, and iron alloys. Alloys of this type have excellent wetting properties, good oxidation resistance, and fair corrosion resistance, but are brittle.

Nickel-manganese, copper-manganese, nickel-germanium, gold-copper, and gold-nickel alloys have also been used as brazing-filler metals in specialized high-temperature applications.

Pure Metals. As the temperature requirements for specific brazed joint applications rise, the trend is toward the diffusion bonding techniques with pure metals used as the brazing-filler metals. Such techniques are by no means new. For example, the electronic industry has used molybdenum as a brazing alloy for tungsten: similarly, rhodium has been used to braze both tungsten and molybdenum. Diffusion brazing with gold and nickel filler metals is relatively common. The use of copper has already been described.

Since little specific information is available on the many joining systems which have been or will be of value in diffusion bonding, it seems best to discuss this technique.

When pure metals are used as the brazing-filler metals, bonding occurs as the result of one of three joining mechanisms. The pure metal may melt at a temperature below the melting points of the base metal: this is ordinary brazing. Diffusion brazing occurs when the pure metal has a melting temperature much higher than that of the base metals: a lower melting alloy is formed by interdiffusion of the base metal. Interdiffusion may occur without the formation of a low-melting alloy. This illustrates one type of diffusion bonding, and another occurs when the base metals are joined by interdiffusion of the same metal.

The Future for High-Temperature Brazing

Brazing for high-temperature oxidation and corrosion resistance has become an important manufacturing technique. The future of almost all industries will rely heavily upon it for successful fabrication of parts for use in a high-speed, high-temperature future. Intelligent application of the present technology and the results of continued research and development show promises of meeting these demands. A short discussion will indicate that present technology and research can broaden the use of high-temperature brazing.

Most of the present high-temperature brazing-filler metals have several characteristics, common to all of them, which limit their use. They have a rather wide melting range and they alloy too readily with the base metals. Actually the deleterious effects of these properties are interrelated: when the melting range is broad, the parts being joined must be held at or near brazing temperature longer, thus promoting alloying with the base metals. A typical example of this problem is encountered when fabricating high strength-to-

weight ratio sandwich structures. In many cases, the core material is completely dissolved and, if it retains its shape at all, is a completely new alloy with poor ductility. The ideal brazing alloy would melt at a single temperature and only alloy with the base metal to the extent that permits it to wet and flow freely.

There are a number of possible ways of overcoming the wide melting range problem, but only a few of them have received significant attention. Very strict attention to thermal cycles, filler metal quantities, and clearances have shown promise in some applications. But, this is only an expedient. Research should be directed toward alteration of the present alloys to narrow the melting range or reduce the alloying tendency. New alloys with more desirable properties should not be beyond the reach of well-planned alloy-development programs. It would also be expeditious to investigate thoroughly the field of barrier layers which will prevent interalloying between the brazing alloy and the metals being joined. A layer of nickel will promote wetting in some cases and it seems reasonable that other coatings may be used to control wetting or interalloying.

Speaking of coatings and barrier layers, here is a whole field of techniques and processes which, when thoroughly understood and applied, should broaden the possible applications of high-temperature brazing immensely.

Many metals and alloys could be satisfactorily brazed if a barrier material were developed to inhibit the occurrence of intermetallic reactions. This is true for applications like silver brazing of titanium or high-temperature brazing of sandwich structures. Barrier layers could be used for another purpose. The use of nickel to promote wetting of refractory oxide-bearing surfaces has been mentioned. A problem concerned with future high-temperature applications will be the increased use of metals having greater amounts of undesirable oxides. New and improved barrier layer techniques may be the best means of making good brazed joints in these alloys.

Diffusion brazing as an established technique for production brazing is in its infancy. Only a few of the possible systems which are amenable to this method of joining have been investigated. There is a large number of metals and alloys which can be plated on an almost equally large number of base metals. The possibilities of these techniques, especially for precision fitted parts, seem almost unlimited. Research in the field of diffusion brazing should be very fruitful in producing joint systems for high-temperature and all other brazing applications.

Another possible use for plating in high-temperature brazing is in preplacing the brazing-filler metal. If methods were available for plating the rather complex filler alloys, either as alloys or in controlled layers of the several elements which would form the alloys at brazing temperature, high-temperature brazing would be simplified. Prebrazing preparation would be minimized, the problem of atmospheres might become less important, and brazing alloy placement would be less difficult.

A whole new area for the application of high-temperature brazing has evolved from the intense activity in the nuclear-energy field. The stringent requirements for precision fabrication of all types of devices for nuclear reactors make brazing a highly useful joining technique in this field. The high temperatures encountered are not exceptional, but the inclusion of some uncommon base metals and strict corrosion requirements make nuclear reactor joining problems quite complex. In addition, other factors such as the need to keep concentrations of high cross-section elements like boron at a minimum, must be taken into consideration.

In the case of atomic reactors for portable power plants, an additional requirement can be placed on brazing-filler alloys. Since shielding must be kept at a minimum, the metals of construction, including brazing alloys, must not contain elements which, when irradiated, form isotopes having long half-lifes. The hazard to people operating and maintaining such reactors would be greatly increased by the radiation from these isotopes. The development of high-temperature brazing alloys to fulfill such needs will be the subject of increasing research efforts.

The solution to these and other problems through concentrated research efforts on many fronts will make it possible for high-temperature brazing to contribute an important part to future progress.

ROLE OF RESEARCH

"The role of scientific research is not only to give a platonic satisfaction to our spirit; it must, by increasing our knowledge of natural phenomena, tend to augment our power of action in the material world. The scientist who, by his works, contributes to the wealth of his country, more fully fulfills his duty than does one who is content to work for art's sake."

Henry Le Chatelier

Dr. Oscar E. Harder

An appreciation

The death of Dr. Oscar E. Harder on July 10 brought to a close the career of a man who made great contributions to metallurgy. Well known as a teacher in the field before he joined Battelle in 1930, he served as assistant director of the Institute until his retirement in 1949. During the following years until his death, he was a consultant on metallurgical research.

From his first days on the Institute staff, Dr. Harder's interests were broad, and their continuing growth was reflected in the expansion of Battelle's metallurgical research activities. He helped promote investigations in the fields of alloy development, physical metallurgy, corrosion, and welding. Growth of research in these fields, aided by his efforts, caused the establishment of separate divisions devoted to each activity. His interests encompassed developments relating to corrosion- and heat-resistant steels, bearing materials, free-machining metals, metal coating, watch technology, heat treatment, and metal fabrication, among others. Resulting accomplishments led to more than 100 patents.

Among Dr. Harder's major achievements, and one always close to his heart, was the development of Elgiloy. Designed for use in watch mainsprings, the alloy has proved to be a desirable material for an increasing number of applications. Lead-bearing free-machining steels, that he developed nearly two decades ago, currently show great promise of contributing to future industrial progress through the expanding production of lead-bearing constructional type steels. Through such examples can be seen the long-range significance of his work.

A very great contribuion was the part he played in the building of Battelle. Dr. Harder possessed uncompromising intellectual honesty, refused to resort to expediencies, and believed that any study could be improved upon, no matter how successful it appeared. These qualities were imparted to the Institute staff and became part of Battelle's working philosophy. At the same time, he was a great believer in cooperation. Through his friendliness, sympathetic understanding, and helpfulness to others, he helped to lay the foundation for team research, one of the great factors in the success of modern research.

His influence was also felt by technologists outside Battelle. He was an active and fruitful member of a half dozen major technical societies. He became president of the American Society for Metals in 1940. Earlier he had led the Minnesota section of the American Chemical Society.

At Battelle, "Doc", as he was known to his friends, was more than a great metallurgist and leader. As one staff member put it: "We will remember him for his sincerity, his gentleness, his understanding, and his truthfulness. He was a generous giver when we sought his counsel and help. Our feeling is that of deep respect and admiration concerning his technical ability, his reputation, and his character as a man and as a genuine friend.

NOTES from BATTELLE

* COBALT-60 TO FRANKFURT

One of Western Europe's first and largest atomic radiation sources has just been installed in Battelle's specially constructed laboratory at Frankfurt am Main, Germany. The source, consisting of 1500 curies of cobalt-60, has a radiation potential equivalent to 15 million dollars worth of radium.

The new gamma-irradiation facility is already in use in research studies being conducted by Battelle for European industry. The facility is expected to play a particularly important role in furthering progress on the radiation sterilization of certain foods, drugs, and medical supplies which are difficult, too costly, or impossible to sterilize by conventional methods. It will also be useful in activating or "triggering" chemical reactions that are vital to the development of better synthetic chemicals and for studies of the effects of radiation on electronic components, lubricants, and other materials.

The source is being used in conjunction with a radiochemistry laboratory that has been operating at Battelle's Frankfurt location for about a year. Battelle's research center at Geneva, Switzerland, will utilize the Frankfurt gamma-irradiation facility as a supplement to its own radiochemistry laboratory.

* BETTER COMMUTATOR ALLOY

Electric motors and generators are being exposed to ever-higher temperatures in many uses. Commutators of soft copper, which were used in early motors, lost much of their strength after exposure to a temperature of 255 F for 10 to 40 hours. Later, the addition of silver (25 to 30 ounces per ton of copper) resulted in commutators that would operate at temperatures up to 450 F. The development of a chromium-copper alloy then followed, which permitted operation of motors at or above 500 F. But difficulties were encountered in the production and handling of this alloy.

Desiring a material that would handle easily and yet provide the needed strength for commutators at temperatures of 500 F or higher the Nippert Electric Products Company sponsored research on the problem at Battelle. Paul W. Nippert of the sponsoring company and Webster Hodge of the Institute report that, after evaluating many alloys, copper containing 0.25 per cent zirconium appeared to meet the requirements best.

Commutators of the new alloy, in many cases, were found to be far superior to silver-bearing copper. Indeed, in one case, an aircraft inverter was run at a temperature so high that the windings of the fields and rotors burned up, but the zirconium-copper commutator remained solid and in good condition. The new alloy also proved to have superior strength and to be easier to fabricate than the chromium-copper. Commutators fabricated from the new alloy are now in production.

Electrical conductivity of the alloy is over 90 per cent of that of the copper standard. Other properties include good machinability, ability to develop and maintain a commutator film, high softening temperature, strength increase with notching, and sufficient ductility to eliminate a substantial amount of cracking in commutator bars.

* GOLD PROTECTS MOLYBDENUM

Considerable effort is being applied to the development of techniques for utilizing molybdenum and its alloys in turbine blades. The metal has good high-temperature strength, but corrodes at high temperatures. In fact, at 1800 F, molybdenum burns rapidly, forming the gaseous compound, molybdenum trioxide. To prevent this burning, the metal can be electroplated with such metals as nickel and chromium, which have good resistance to high-temperature air.

Technologists at Battelle discovered that the molybdenum underneath the protective plate could still come in contact with air along the microscopic boundaries between grains of the nickel and chromium. In an attempt to prevent such damage, Battelle technologists tried an experiment with gold.

After plating their molybdenum specimens with one layer of chromium, they plated a thin layer of gold onto the chromium. This was followed by additional layers of nickel and chromium. When the specimens so treated were exposed to high temperatures, it was found that the gold had formed a layer that effectively

retained the molybdenum, allowing the nickel-chromium coating to do its job of protecting the entire part.

This discovery was made during the course of a basic research program on the high-temperature properties of electroplates, conducted by Battelle for the Navy Bureau of Aeronautics. The results of this research were reported earlier this summer at the 43rd Annual Convention of the American Electroplaters' Society, Washington, D. C., in a paper, "Properties of Electrodeposits at Elevated Temperatures", by W. H. Safranek and G. R. Schaer of Battelle.

* HIGH-TEMPERATURE MONOGRAPH

Because of needs felt by members of the Electrochemical Society for a summary of recent developments in the high-temperature field, a monograph entitled *High-Temperature Technology* recently has been published by John Wiley & Sons, Inc. under the sponsorship of the Society. Editor of the volume is I. E. Campbell, chief of Battelle's inorganic chemistry and chemical engineering division.

He has selected 35 papers for inclusion in the volume. They are divided into four main parts covering (1) development of modern refractories, (2) materials, (3) methods, and (4) measurements. The Materials Section reviews well-established materials and discusses the newer ones about which information is available. The Methods Section presents information on various types of furnaces and other means of securing very high temperatures. A critical discussion of temperature and equipment for its measurement is found in the Measurements Section. In general, consideration is given to service above 1500 C.

* DUCTILE MOLYBDENUM

Cast molybdenum has good ductility at room temperature when it is sufficiently pure. However, it is difficult to reduce the oxygen, nitrogen, and carbon content of the metal to the point where molybdenum will be ductile. L. E. Olds and G. W. P. Rengstorff, Battelle metallurgists, reasoned that the harmful effects of the impurities might be neutralized by small amounts of alloying additions. Therefore, they and their colleagues investigated the effects of additions of elements that might form stable oxides or nitrides that would not be harmful to ductility or that might increase the solubility of the impurities in the molybdenum.

Of the alloying additions studied, the metallurgists found that titanium, when added in amounts of 0.5 to 1 per cent, was most effective for improving low-temperature properties of molybdenum which contains limited amounts of oxygen and nitrogen.

Other additions, in order of their effectiveness, were 10 per cent thorium, 0.026 per cent aluminum, 0.15 per cent cerium, 0.5 per cent vanadium, and less than 0.25 per cent zirconium.

Improvement in ductility by additions of thorium in large amounts, 3 to 10 per cent, is believed to result from a mechanism different from that operating in connection with the other alloying additions. Rather than deoxidation, the improvement appears to result from the presence of a soft envelope of substantially pure thorium at the grain boundaries, which offsets the usual intergranular brittleness of molybdenum but at a sacrifice of high-temperature strength.

* PULSATIONS IN FURNACES

Pulsations are one of the most annoying and costly problems for manufacturers, distributors, and users of residential heating equipment. Furnaces and boilers "in pulsation" have been known to radiate sound energy intense enough to damage a house or its contents. Attempts to correct such conditions generally have been unsuccessful because the exact nature of the pulsations has not been understood.

Research now going on at Battelle for the American Society of Heating and Air-Conditioning Engineers, the Oil-Heat Institute of America, and the American Gas Association has shed some light on these problems. Battelle technologists A. A. Putnam and W. R. Dennis report some preliminary results of their studies to the semiannual meeting of the ASHAE in Washington.

Working with experimental gas- and oil-fired furnaces, they made motion-picture studies and tests in which important factors, such as air-fuel ratio, are varied and their effect on the pulsations noted. Thus far the studies have shown that:

1. For the oil-fired unit, the important factors in pulsations were definitely indicated to be (a) the relative flow patterns of fresh air, hot products of combustion, and fuel, and (b) the relative position of the combustion zone and pressure antinode.
2. For the gas-fired unit, the most important variable appeared to be the rate of flow of primary air.
3. As shown by motion-picture studies, the mechanisms for driving of pulsations are related to periodic, rapid flame expansions for the oil-fired unit and a vortex shedding for the gas-fired unit.

PROCESSING POULTRY WASTES

United States Department of Agriculture specialists say that the total value of raw offal and feathers from poultry plants would be $3 million a year if the waste could be processed into protein feed products and grease. Currently, full use of waste is found only in a few plants in principal broiler areas, the USDA reports, largely because present waste recovery techniques are expensive and because much of the processing is done in separate renderers' plants rather than at poultry slaughtering plants.

A study by the USDA and Battelle will seek to determine whether it is economically feasible for poultry plants to process their own wastes into by-products that could be readily sold. Included in the program is an investigation of methods for handling and processing wastes within poultry slaughtering plants and the determination of poultry and rendering plant sizes and facilities necessary to profitably process the wastes.

VIEW OF VAPOR-PLATING

A unified picture of the "art" of vapor-plating by chemical processes is presented in a new volume, *Vapor-Plating*, sponsored by the Electrochemical Society. The authors of the book are C. F. Powell, I. E. Campbell, and B. W. Gonser, all of Battelle.

They describe and critically evaluate vapor-plating techniques and discuss conditions required for depositing pure metals, carbides, nitrides, borides, silicides, and oxides from gaseous mixtures of their vaporized compounds. The book, however, is not intended as a comprehensive reference. Rather, it is written to present vapor-plating as it is today, both as an art and as a growing science, and to stimulate further research in the field. The book was published by John Wiley & Sons, Inc.

* Henry A. Saller, a pioneer in the field of nuclear research, has been named assistant technical director at Battelle. His first important assignment in atomic research, also an historic one, was as consultant in the fabrication of the first 50 tons of uranium for the prototype of the Hanford piles. In the years since, as chief of Battelle's reactor metallurgy division, his work has covered the metallography alloy development, and fabrication of uranium, thorium, beryllium, zirconium, and other metals of importance to reactor technology.

* Dr. Eugen Dumont has been appointed chief of the plastics chemistry division at Battelle's Frankfurt laboratory. He has been associated with that division since joining the Institute in 1954. Previously, over a period of 18 years, he had carried on research in plastics for private industry and had served as plant manager for German firms engaged in the production and application of plastic materials. Dr. Dumont, who received his doctorate from the University of Bonn, is author of more than 30 publications and holds seven patents in his areas of specialization.

* "The Study of Copper Anodes in Acid and Cyanide Plating Baths", by C. L. Faust and W. H. Safranek of Battelle, was selected as the best technical paper to appear in the publications of the American Electroplaters' Society during 1955. The Carl E. Heussner Award, which is presented annually to the authors of the year's best paper, was received by the two technologists at the recent meeting of the society in Washington, D. C.

* Battelle Institute has been awarded a contract by the Atomic Energy Commission for critical assembly studies of a small heterogeneous boiling water reactor for military application. These studies, extending over the period of a year, will be conducted by Battelle in its recently completed reactor development (critical assembly) laboratory.

The objective of this study is to determine the range of usefulness of a control system in which the reflector is used to control the reactor rather than control rods as is the more conventional technique.

* The increased demand for high-temperature materials often requires the determination of their stable phases by observation of metals and ceramics at elevated temperatures. A. E. Austin, N. A. Richard, and C. M. Schwartz of Battelle report that an X-ray powder diffraction camera has been designed and constructed at the Institute which makes such study possible. The apparatus permits the study of materials in a high vacuum to temperatures of at least 2000 C. It also allows work in controlled atmosphere at elevated temperatures and permits successive exposures of the specimens while they are held at temperature.